

bus, nimbus, cumulus, stratus, was so determined that we now know the average height of each type for every month in the year, and the depth of the zone or horizontal belt in which they may severally occur. Thus the upper types are found in layers as much as 6 miles thick, though they form most frequently near the middle of their respective belts; the lower are thinner, and have some peculiar characteristics besides. When we consider that the height and shape of these belts, changing from month to month, indicates some very delicate physical process going on in the aqueous vapor of the atmosphere, it is easy to see that they become the best means for studying the state of the pressure, temperature, and vapor tension—that is, the physics of the air itself.

2. A very important subject has been the determination of the direction and velocities of the horizontal motions of the air in each of the eight principal levels, on all sides of the anti-cyclones and cyclones, high and low areas of pressure, as they move over this country. These movements have been separated into two components, the first belonging to the general or undisturbed motion of the atmosphere, which is about eastward in this latitude, and the second pertaining to the local motions, which are gyratory, and especially concerned with the descending and ascending vortices or storms. This data gives us for the first time definite information regarding storm components, and these enable us to look into the theories much more closely than heretofore.

3. This analysis has been supplemented by a compilation of cloud motions taking place in the cumulus or the cirrus levels, as derived from the Weather Bureau cloud charts collected during the past twenty years, the object of which is to show how the average anticyclone and cyclone are affected by the circulation of the air over different parts of the United States—that is, by the Rocky Mountains, the Lake region, the Gulf of Mexico, and the Atlantic Ocean—the results being exhibited on a series of colored charts.

These practical facts lead to the necessity of definite theoretical studies in order to account for them, and this again to several other lines of research:

1. The first step was to prepare a system of standard constants and formulæ by a comparative study of the papers of several authors, and by the addition of such new demonstrations as seemed desirable, so that the work of many men in their several branches may be read as one consistent meteorological scheme. This standard system represents the outcome of several years' study of the subject. These formulæ include most of the thermodynamic or hydrodynamic conditions likely to arise on a rotating body surrounded by an atmosphere, like the earth.

2. Next, a completely new set of working tables, based upon these formulæ, has been prepared for the barometric reductions from one level to another; for studying with the greatest accuracy the exact conditions of pressure, temperature and vapor tension at the level where a cumulus cloud base forms by the vertical convection, at the place where the hail forms, and at the level where the snow is produced; and finally for computing the dynamic forces and the gradients of motion according to the observed velocities. These tables are permanently useful to meteorology, and that they are needed is seen from the following considerations: (a) The Smithsonian tables and the International tables are adapted for the reduction from elevations 2,000 meters or less to the sea level; but in cloud work it is necessary to reduce at will throughout a region up to 15,000 meters in height and with ranges of temperature from $+30^{\circ}$ to -60° C., which is far beyond the limits of any existing tables. (b) The Hertz diagram for adiabatic expansion leaves out the vapor contents of the air in parts of the formulæ, introducing errors of as much as 0.30 inch in pressure. Besides, it is desirable to

be able to start with surface conditions and compute upward in exact figures all the elements existing in the cloud, and also the gradients connecting one level with another. (c) Since the atmosphere differs very widely from the adiabatic laws, one of our problems is to discuss how large this departure is for all seasons of the year, and from this data we expect to study carefully the laws of solar insolation and terrestrial radiation—that is, the actinometry of the atmosphere—by means of the new and improved material. (d) Finally, there are no tables published which are available for computing the dynamic forces indicated by the equations, and these are necessary if meteorology is to be made an exact science.

3. The possession of all this new matter enables us to analyze closely the Ferrel theory of the local cyclone and the German theory of the same, which differ from each other, and to show that they are both only ideal solutions of vortices, and do not conform to the stream lines given by the observations. An attempt has been made to interpret the analytical equations of motion, so that they shall match the observed facts, and this leads to a different idea of the circulation in storms from that commonly taught by meteorologists. The application of the theory to tornadoes is certainly satisfactory, and in the case of hurricanes and cyclones it is on the whole very promising.

FLOODS AND FLOOD PROBLEMS.¹

By H. C. FRANKENFIELD, Forecast Official, U. S. Weather Bureau, Washington, D. C.

You have discussed, or will discuss, many methods for the improvement of commerce, and the consequent increase of wealth to the country. Of equal importance is the discussion of ways and means looking toward the prevention of loss and damage, and the consequent diminution of wealth, the effect of which would be far-reaching. To this latter branch of your work I have been directed by the Chief of the Weather Bureau to contribute, and I will endeavor to do so by presenting for your consideration a paper on "Floods and Flood Problems of the Mississippi River." About 40 per cent of the entire population of the United States live within the watershed of the Mississippi River, the basin comprising about two-fifths of the total area of the United States; and I therefore submit that any information, however slight, which will contribute to the material welfare of a very considerable portion of this district is worthy of proper consideration.

It may be of interest, by way of preface, to make some brief historical mention of the great floods of the Mississippi system. Nothing except comparatively faint tradition exists regarding the floods preceding those of the present century. In April, 1785, the Mississippi River at St. Louis was said to have reached a stage of 42 feet, or 0.6 feet higher than the well-authenticated stage of June 27, 1844. You all remember the destruction that was wrought by the flood of 1892 in the vicinity of St. Louis. Yet the highest stage reached by the waters in that year was only 36 feet. Conceive, if you can, what would have happened had an additional 6 feet of water been added to the flood volume.

Since the commencement of the present century the notable flood years were 1815, 28, 44, 49, 50, 51, 58, 59, 62, 65, 67, 74, 82, 84, 90, 92, 93, and 97.

Of these the floods previous to that of 1874, while entirely authentic as to occurrence, are not equally so as regards the exact stages of water reached, with the exception of that of 1858, which was the subject of careful and accurate measurement. This lack of exactness was due to the absence of regular

¹An address delivered at the Tenth Annual Transmississippi Commercial Congress, at Wichita, Kans., May 31, 1899.

gage readings which could be referred to a definite standard. Since 1867, however, there have been abundant gage readings, and, as a result, the flood stages are much more comparable, both as to volume and effect. Still, making due allowance for possible errors and deficient records, there is no doubt that the flood of 1844 was the greatest ever known in the upper Mississippi basin, while that of 1897, as a whole, was the greatest ever known south of the mouth of the Ohio River. From the best obtainable information the highest water of which there is reliable record occurred at the principal cities in the Mississippi basin as follows:

Station.	Stage.	Date.
	<i>Feet.</i>	
St. Paul, Minn.....	19.7	April 19, 1881.
Omaha, Neb.....	23.8	April 24, 1881.
Kansas City, Mo.....	24.0	May 21, 1892.
St. Louis, Mo.....	41.4	June 27, 1844.
Cincinnati, Ohio.....	71.1	February 14, 1884.
Cairo, Ill.....	52.9	February 27, 1893.
Memphis, Tenn.....	37.1	March 19-21, 1897.
Vicksburg, Miss.....	52.3	April 16, 1897.
New Orleans, La.....	19.5	May 13, 1897.

There is a tradition that a stage of 37 feet was reached at Kansas City, on June 20, 1844. I can not conceive of such an immense volume of water at this place; but as there is a tradition of similar stages at the same time along that portion of the Missouri River east of Kansas City, it is probably not far from being correct.

The flood question may be resolved into two general divisions, cause and remedy; both admitting of subdivision into various parts, each contributing to a greater or less extent toward the effectiveness of the whole.

The cause of floods is of course the precipitation which occurs over the basins of the rivers affected. Of the total amount of water which falls, a portion flows off into rivulets, drains, and small tributaries, finally reaching the main river. The remainder sinks into the soil, is absorbed by vegetation, or else is evaporated. The proportion of rainfall which reaches the main rivers depends upon the condition of the soil and the steepness of the slopes. Where the soil is very dry and absorptive, as in the upper Missouri Valley, nearly all of the water will be absorbed, comparatively little reaching the main river. In the bottoms of the lower Mississippi, however, where the soil is almost completely saturated with moisture, and where the rainfall is excessive, a very large proportion of the water will be discharged into the river.

The steepness of the slope of the river basins also exercises an important bearing upon the amount of water which reaches the main streams. Where the fall is comparatively steep, a much greater quantity of water will run down to the river than if the slope were gentle, the rapidity of movement preventing much absorption by the soil.

Contrary to the impression obtaining among most people, the melting snows in the mountains contribute but little to the floods of the Mississippi. As a matter of fact, nearly all of the floods come at a season when the flow from the mountains is very small. Colonel Chittenden, of the Corps of Engineers, U. S. A., in his report on Reservoir Sites in Wyoming and Colorado, says that in the greatest known flood of the Mississippi at St. Louis, that of 1844, a large part of which came from the Missouri, the latter stream was at low water stage at Sioux City, and that during the flood of 1897 neither the Arkansas nor the Platte rivers contributed any appreciable amount of water from their western portions, and that the upper Missouri and Yellowstone were both at low water stage.

The floods of the Mississippi above the mouth of the Ohio are neither so frequent, nor so extensive, nor so prolonged as they are below. Their sources of supply are fewer and smaller and the rainfall is not so abundant. From the mouth of the

Missouri to the mouth of the Ohio the waters of the former are the decisive factors in flood production, and there can be no flood south of Alton, Ill., unless the Missouri east of Kansas City is in flood at the same time. A few figures will suffice to prove this. If the Mississippi at Grafton, Ill., is discharging 450,000 cubic feet of water per second, corresponding to a stage of 28 feet, or 5 feet above the danger line, and the Missouri at St. Charles, Mo., is discharging 375,000 cubic feet per second, corresponding to a stage of about 25.5 feet, or about 6 feet above the danger line, the combined discharges, 450,000 + 375,000, or 825,000 cubic feet, must be the amount of water that passes St. Louis every second, there being no intervening tributaries. This corresponds to a stage of about 34 feet, or only about 4 feet above the normal danger line, and supposes that both the Missouri and Mississippi are in flood. Now suppose the discharge at St. Charles, Mo., to be decreased to 175,000 cubic feet per second, corresponding to the danger line stage of 20 feet, still comparatively high, while that at Grafton, Ill., remains at 450,000 cubic feet. The total discharge will be 450,000 + 175,000, or 625,000 feet per second for the St. Louis gage. This corresponds to a stage of about 29.5 feet, or 0.5 foot below the danger line. On the other hand, it is possible to have a moderate flood from Alton to Cairo, Ill., while the Mississippi above the former place is at a medium stage. It is estimated that in times of flood about 70 per cent of the water which passes St. Louis, comes out of the Missouri River.

But the floods of the upper Mississippi are rarely extremely destructive, and at St. Louis improvements of such a character have been made since the flood of 1892 that less damage would be caused by a 36-foot stage, or 6 feet above the technical danger line, than would have resulted from a 32-foot stage at that time. It is only below Cairo, Ill., that the floods become such potent factors for evil, and thrust themselves into the foreground as one of the great economic problems which confront the business life of the country.

By far the most important source of these lower Mississippi floods is the immense volume of water which flows out of the Ohio River with its numerous, and extensive, and swift-flowing mountain tributaries on the south, and the slower-running and less important ones on the north. During the flood of 1897, when on March 26, the water at Cairo, Ill., reached its crest stage of 51.6 feet, the discharge of water was about 1,650,000 cubic feet per second, while at Helena, Ark., with a maximum stage of 51.3 feet on April 4, it was about 1,750,000 cubic feet per second. This is about 150,000 or 200,000 more cubic feet than finally passed Vicksburg and New Orleans, and the difference may be taken to fairly represent the amount of overflow, after deducting a slight portion due to loss by evaporation and other less important causes. This overflow is either distributed among the open swamps or bayous, or runs into the Yazoo and Red rivers as back water, or last, but unfortunately not least, breaks through levees or rushes over banks, causing the widespread ruin and disaster with which many of you are familiar. I quote in this connection from Prof. Park Morrill's exhaustive work on Floods of the Mississippi River, which was issued by the Weather Bureau after the great flood of 1897, he says:

It is, of course, conceivable that a flood should occur in the lower Mississippi from heavy precipitation over any of the great contributory basins. In these floods of the past quarter century we do not, however, find the western tributaries playing an important part. The great source of floods is the Ohio basin, with its steep slopes from the crest of the Alleghenies, upon which fall the heaviest rains of spring at a time when the normal rise of the lower Mississippi brings the river almost to the danger line from Cairo to the Gulf. In the greatest floods we also find that heavy rainfall over the great swamp region, that extends along the Mississippi from the mouth of the Ohio to the Gulf of Mexico, is an important factor. Third in importance as a factor in producing floods is the upper Mississippi, which, while never discharging a volume sufficient to produce of itself a flood, yet, rising later than the Ohio, serves to prolong the high water, and thus to increase the overflow.

It is well that even at times of greatest floods there are ameliorating circumstances. Otherwise there would be no recovery from the enormous losses which would inevitably ensue. Over most of the districts liable to overflow the drainage is excellent; the slope is away from the river, and the water does not spread rapidly. There is plenty of time to save life, remove portable property, and take all necessary precautions. Consequently the loss, beyond the interruption to business, is confined to the destruction of crops, buildings, fences, etc.

The flood of 1897, the greatest of lower Mississippi floods of which there is authentic record, with the possible exception of that of 1882, may be said to have owed its origin to the heavy rains of January of that year in the Mississippi and extreme lower Missouri valleys, causing the rivers to rise somewhat higher than the usual midwinter stages. These conditions were much intensified by a continuation during February, of the excessive rains over the lower Mississippi valley, and their extension through the Ohio Valley and its entire tributary country. Flood stages resulted from these downpours, and the Ohio at Cincinnati reached a stage of 61.1 feet on the 26th, and at Cairo of 40.0 feet on the 28th. Meanwhile the entire Mississippi was rising rapidly. It remained for the precipitation of March to complete the work so well begun, and an inspection of the rain chart for that month will show you how completely and effectually it was enabled to do so. From this time on the flood occurrences are matters of history familiar to all of you.

The function of the Weather Bureau in times of flood is limited to the issuance of the necessary warnings a sufficient time in advance, to afford opportunity to remove all portable property to places of security, and to make the best possible disposition of that which cannot be moved. This involves extremely accurate forecasting of the stages which will be reached at each place, and the times when they will occur. It necessitates an intimate acquaintance with the entire river regime, the effects of local and general rainfalls, tributary streams, drainage basins, and levees, and also requires rapidity and accuracy of judgment when sudden changes are impending by reason of crevasses, etc. At such times the weight of responsibility resting upon the shoulders of the forecasters is tremendous, as a single error might result in enormous loss of life and property. I believe I may safely say that the work of the Weather Bureau during this flood was well performed. The warnings issued were so complete and far reaching as to cause criticism in some quarters that the Bureau was needlessly alarming the people of the threatened districts. The criticisms were unfounded, however, as the warnings were fully justified by the events.

About 13,500 square miles of land were overflowed, and portable property to the value of \$15,000,000 removed to places of safety, mostly as a result of the Weather Bureau warnings. The total expense of the River and Flood Service of the whole United States for the entire year of 1897 was about \$15,000. Compare this insignificant sum with the value of the property saved. As a business proposition does it not commend itself to you? Can you imagine a better return for an investment?

With a full realization of the fact that the floods must come, and that they must cause an immense amount of damage, which, under present conditions, can not be avoided, let us now pass to the second phase of the flood question, namely the remedy. Is there a remedy? There are said to be several, and each and all have been discussed *verbatim et literatim et scriatim*. In general, however, there are the advocates of the all levee system, those of the no levee system, and those who believe in the use of both levees and reservoir basins, the character of protection depending upon the topographical conditions. All, however, except a few old line extremists, are united in support of the levee system in some form, their differences being mainly of degree only.

The first query which naturally arises is, Is the levee system effective? If so, is it sufficiently effective to warrant the continued expenditure of money at the present rate to keep it so? And, if so, will it remain at its present state of efficiency without additions, and with only those repairs which are necessitated by crevasses and the natural wear and tear incident to age?

The second query which presents itself is—If the levee system is not effective, can it be made so by the expenditure of any sum of money within reason? If not, what remedy can be offered, which, while preventing flooding of the farms and plantations, will at the same time have a due regard for the interests of navigation?

In answer to the first question it must be admitted that the levee system is effective if the levees are properly constructed. That is, it is effective now, but along the lower Mississippi it is questionable whether it will remain so in future floods. Why, I will endeavor to explain later.

Taking the levees as they stood in 1897, I think I am correct in saying that many of those which failed to withstand the flood of that year were admittedly not as well constructed as they might have been. No criticisms of methods is implied in this statement, for it is not in the least to be doubted that the broken levees were built as substantially as was possible under the existing circumstances. The supply of funds for levee construction was limited, and had to be distributed over too large a territory. The United States Government levees were built according to a certain standard and with more ample funds, and, as far as I have been able to learn, no Government levee gave way to any extent in 1897.

As the floods above Cairo, Ill., are of minor importance on account of their comparatively infrequent occurrence and limited extent, so also is that of flood protection over the same district. Nevertheless, what could be done has been done, or shortly will be, and it has been done effectively. From St. Paul to the mouth of the Missouri River, a distance of about 700 miles, there are subject to overflow at times of high water 564,200 acres of land, or about 882 square miles, of which over one-eighth lies within the last 50 miles, between Cap Au Gris, Mo., and the mouth of the Missouri River. From Keithsburg, Ill., to Burlington, Iowa, a distance of a little over 25 miles, there is the Flint Creek levee on the Iowa side which protects 44,000 acres of land. From Warsaw, Ill., to Hamburg, Ill., a distance of about 110 miles, there are the Warsaw and Sny levees, with the exception of a gap of less than 20 miles between Quincy, Iowa, and Hannibal, Mo., which is in course of construction. These two latter levees protect 210,000 acres of the finest farm land in the world, making a total of 254,000 acres, or about 397 square miles, which are now protected, or nearly one-half as much as is now subject to overflow. When the new levees are built where needed from Burlington, Iowa, to Hannibal, Mo., the total area liable to overflow will be reduced decidedly, but exactly to what extent I am unable to say.

I am informed that the building of the levees has raised the value of the lands protected \$5 per acre in some localities and \$25 or even more in others. This shows that the money expended in levee building has been well applied, and that the levee system in this district is effective. It can be kept so, and will remain at its present state of efficiency with only a moderate outlay each year for repairs. The all levee system meets with unanimous approval, and more levees are wanted.

Below Cairo, Ill., however, where the greatest interests are at stake, opinions differ radically, and it becomes an extremely difficult matter to determine exactly what is the true solution of the problem. It has been charged by the enemies of the all levee system that millions of dollars have been squandered in attempts to build levees that will not withstand

flood waters, and that it is impossible to build levees that will suffice for the combination of waters such as is possible. Another class goes to the opposite extreme and asks for the old system when the surplus waters ran into the large drainage basins, the bayous, and the sloughs, overflowing millions of acres of land which are now reclaimed, at least partially, and finally finding its way back into the main channel, thereby greatly prolonging the flood period.

Between these two antipodal opinions some middle ground must be found which will afford the greatest possible measure of protection at a not too impossible cost.

The plan of reversion to the old open basin and bayou drainage can be dismissed without a word as being alike uncharitable and unworthy of this age and time, and also impossible from a social and economic point of view.

The all levee plan, that of closing all the basins and compelling the river to run between well defined banks from Cairo, Ill., to the passes, sounds very plausible, and indeed is so as far as the possibility of construction is concerned. The levees would have to be raised higher all along the line, as the narrowing of the channel would increase the height of the flood levels, but the work could be done. According to competent authority a grand chain of levees sufficient to keep out any flood could be built from Cairo to the Gulf of Mexico for about \$20,000,000, to which must be added an annual charge for repairs of at least 10 per cent, and probably more. It is also probable that difficulties, at present unforeseen, would increase the original cost to an amount in the neighborhood of \$25,000,000, with the same percentage for annual repairs. Even then, according to some authorities, the desired goal would not be reached. The constantly caving banks, amounting in some places to one foot a day, or 365 feet in a single year, deposit an immense amount of earth in the river, and a great quantity of it remains, gradually bringing up the bed of the river, so that, with the levee system complete, each flood would require a smaller volume of water to produce the same effects as the preceding one. Therefore, to render the all levee system perfectly effective, in addition to the building of the levees the banks on both sides of the river must be protected by revetments, and this work is extremely expensive. The revetments would cost about \$100,000,000, and I have heard estimates as high as \$175,000,000. Assuming the former figures to be correct, and adding to the \$100,000,000 the \$20,000,000 for the proposed new levees, and we have \$120,000,000 as the cost of the completed work, to which must be added several millions more each year for repairs.

The power of a levee to effect the stage of the water is excellently shown in the following statement, relative to the effect of the new St. Francis levee upon the flood of 1897, by Mr. S. C. Emery, the official in charge of the Weather Bureau office at Memphis, Tenn., which was published in Professor Morrill's work on the Floods of the Mississippi River. Mr. Emery says:

Before comparisons can be made between the present flood and those which have occurred in former years, it is necessary to take into account the changed conditions which have resulted from the construction of the Arkansas levees. Since 1890 there has been built a line of levee along the west bank of the Mississippi River, extending from Point Pleasant, Mo., south to Pecan Point, a distance of 125 miles. The purpose of the levee is to protect the St. Francis bottoms, the greater portion of which was formerly subject to an annual overflow. Of this bottom much is not under cultivation, considerable areas being covered by a succession of swamps and lakes, having a heavy growth of gum, sycamore, and cypress trees. In former years the bottom had been flooded more or less whenever the Mississippi at Cairo reached a 41 or 42-foot stage. The water after leaving the main river passed into the St. Francis basin, through which run the Little and St. Francis rivers; through these channels it again found its way to the Mississippi at a point about 12 miles north of Helena, Ark. The effect of leveeing the west bank of the Mississippi in front of the St. Francis bottom is to compel the water to pass down the Mississippi from Cairo to Helena.

In the following table a comparison is made of several earlier floods with that of this year. The floods occurring from 1882 to 1886 reached

about the same stage at Cairo as the flood of this year. The maximum stages at Cairo, Fulton, Memphis, and Helena, during the floods of 1882-1886, together with their mean, and the corresponding stages of this year's flood, are presented.

Year.	Cairo, Ill.			Fulton, Mo.		Memphis, Tenn.		Helena, Ark.	
	Maximum stage.	Maximum stage.	Below stage at Cairo.	Maximum stage.	Below stage at Cairo.	Maximum stage.	Below stage at Cairo.	Maximum stage.	Below stage at Cairo.
1882	51.8	36.7	15.1	35.0	16.8	47.2	4.6		
1883	52.2	36.3	15.9	34.8	17.4	46.9	5.3		
1884	51.8	35.7	16.1	34.2	17.6	47.0	4.8		
1886	51.0	35.4	15.6	34.8	16.2	48.1	2.9		
Mean	51.7	36.0	15.7	34.7	17.0	47.8	4.4		
1897	51.6	37.4	14.2	37.1	14.5	51.8	0.2*		

* Above.

The average difference in stage in the earlier floods between Cairo and Fulton was 15.7 feet; between Cairo and Memphis, 17.0 feet; and between Cairo and Helena, 4.4 feet. The building of the levee has caused a decrease in the difference between these points; that is, it has raised the stage at Memphis about 2.5 feet above what it would have been had the water been left to flow over the lowlands of Arkansas. So, instead of a difference of 17.0 feet between the Cairo and Memphis stages, we now have about 14.5 feet, and, had it not been for the breaking of the levee, it is probable that this difference would have been lessened at least an additional foot. In other words, the levees, if kept intact, would result in some 3 feet more water at Memphis than under former conditions. At Helena the change is still more marked, and the former difference of 4 feet has entirely disappeared, and, had it not been for the great crevasse at Flower Lake, the Helena flood crest would have been considerably above that at Cairo.

Another proposed plan of relief is to select some large basin of sufficient area as a reservoir to hold the surplus flood waters, thereby admitting of levees of more moderate heights, and at the same time conserving the surplus waters until such time as they may be needed to aid navigation during the low water seasons. It is the opinion of competent engineers that no such reservoir could be constructed in the Ohio Valley, and that, consequently, a site must be looked for further down. The St. Francis basin with its area of 6,706 square miles is the one toward which the eyes of the engineers have been mostly turned. Mr. James A. Seddon, assistant engineer of the Missouri River Commission, has estimated that to take care of the surplus waters on the Cairo gage above the height of 44 feet would require a reservoir of 4,655.6 square miles in extent and 10 feet deep. If the depth should be increased to 15 feet, the area required would be reduced one-third, or to 3,103.7 square miles. This immense quantity of water could be stored in five or six reservoirs, into which the basin could be subdivided by means of cross levees, and set free at low water times when needed for purposes of navigation. It is claimed that with this surplus there would always be sufficient water for the heaviest draft steamboats below Helena, provided the proper amount of care were exercised in disposing of it. The cost of this work is variously estimated at from \$40,000,000 to \$50,000,000, including compensation to private citizens for property, or about \$70,000,000 cheaper than the cost of leveeing the whole river and revetting its banks. It is also presumed that the cost of the necessary annual repairs would not be so great. By this means the flow of water would be materially reduced, the flood danger below minimized, and the levees would not have to be built so high, even though the Yazoo, White, and Tensas basins, with their 13,000 square miles of territory, were to be permanently closed.

It has been frequently suggested that a high water canal could be cut through at Bonnet Carre, La., from the river to Lake Pontchartrain, and thereby relieve the situation below in times of flood, especially at New Orleans. This scheme had some advocates, and likewise some bitter enemies. The

possibilities of the case, as near as I can compute them, are as follows, taking the flood of 1897 as the maximum condition, and the danger line of 45 feet at Vicksburg as the line above which the water would begin to run off into the canal. At the time of the maximum stage of 52.3 feet the discharge in cubic feet per second was about 1,600,000, while at the 45-foot stage it was about 1,300,000. The difference of 300,000 feet is the quantity which it is desired to dispose of through the proposed canal. Assuming the velocity of the current to be 4 miles per hour, which is equivalent to 5.87 feet per second, the cross section of the canal would have to be $300,000 \div 5.87 = 51,107$ square feet. Therefore, if the depth were to be 30 feet, the width would have to be $51,107 \div 30 = 1,703.6$ feet, and its length would be about 12 miles. Both banks would need protection by revetments to secure permanency. I can give no close estimate of the cost of such a work, but I think it could be done for \$20,000,000 or less. On paper it certainly appears feasible. Opponents of the canal argue that it would gradually fill up by deposits of sand, but this objection is met by the reply that it applies equally to any portion of the river, and the canal, owing to its comparatively limited extent, could be effectually dredged to the required depth whenever necessary.

Above the mouth of the Missouri attempt has been made to lessen the flood heights by building storage reservoirs at the head waters. Five of these reservoirs were built, with a view to store surplus waters, which should be available for purposes of navigation when the low-water season set in. These anticipations were not realized, however. The floods were repressed to some extent as far as Lake Pepin, but not below, and as much as 1 foot of additional water was available at the low-water season at St. Paul, disappearing by the time Redwing, Minn., 52 miles below, was reached. In any event, with or without reservoirs, no floods north of Lake Pepin are felt to the southward to any considerable extent.

The effect in the lower river of an all levee system upon navigation would be to narrow the channel and, consequently, increase the velocity of flow during high water, thereby retarding somewhat the upstream movement of boats. Relief would come quicker, however, owing to the greater velocity of the water, as it would, of course, run off sooner. In times of low water it is probable that, there being no overflow or back water to run into the main stream and the levees causing a greater velocity in the flow of the water already there, the low-water season would be prolonged and still lower stages prevail than had obtained in the past. This would be impossible with the storage reservoir, as the surplus water could be let into the river just as needed.

This completes about all I have to say upon this subject, and I beg of you to bear in mind that I do not come here as an expert in these matters; I simply present to you the facts as I have gathered them in various ways. The subject is certainly one of deepest importance, and justifies almost any expenditure of time and money to produce satisfactory results. The proper improvement of the Mississippi River may require thirty or forty years of time and may cost \$300,000,000. It could probably be done in one-half the time and for one-half the money or less. But no matter what the cost, the moral, social, and economic development of many millions of people is directly concerned, and it is not always wise to too closely reckon the cost in mere dollars and cents.

SMALL WHIRLING COLUMNS OF MIST.

By RALPH B. MAREAN, Weather Bureau, dated October 25, 1899.

On Sunday, October 22, a very interesting meteorological phenomenon was observed by me at the upper or receiving reservoir on the Conduit road a few miles above Washington. It was about 7:30 of a perfectly clear, calm, frosty morning.

Over the mirror-like surface of the pond hung a ragged mist from 5 to 10 feet deep and so thin that it did not obscure objects on the opposite shore, some three hundred yards distant. When first seen there was no perceptible movement in this veil of mist; it rested almost motionless on the surface of the lake. Soon, however, it was noticed that it had begun to drift hither and thither in all directions. In two places within 50 or 100 feet of each other the movement would be in opposite directions. Almost simultaneously with the beginning of this movement of the fog there appeared whirls or spouts in the mist, seeming to form where two nearly opposite currents of air met, as shown by the drifting mist. Some of the columns were evidently formed as rolls between two parallel opposed currents. When first formed these spouts were from 2 to 4 feet in diameter, extending but 2 or 3 feet above the surface of the water and rotated (counter clockwise) but five or six times per minute. The speed of rotation rapidly increased, however, until at the end of half a minute or so it would be about thirty or forty per minute, the diameter decreasing at the same time to from 6 to 18 inches, while the column grew until about 20 feet in height. The column appeared hollow, the denser mist being in the outer ring. In the fully developed whirls there was a well defined upward spiral motion, the angle of ascent being, as nearly as could be judged, between 45° and 60° with the horizontal. Although some of these spouts lasted probably as long as five or six minutes, their average life was about two minutes, but within the twenty or twenty-five minutes during which the phenomenon was observed a great many, probably over a hundred, of these little whirling columns of mist were seen. Generally they had no progressive motion, although a few wandered aimlessly here and there. Gradually the number of the spouts diminished and finally in about half an hour no more were formed, the mist in the mean time having become almost entirely dissipated, partly by the rising sun and partly by the mixture of dry air.

Of course one could not witness a phenomenon of this kind without trying to discover its cause. It seems to the writer that the lower stratum of air had become heated by radiation from the comparatively warm water, but as no disturbing incident occurred it lay in the hollow over the lake in a state of unstable equilibrium. As soon as something happened, however, to disturb this equilibrium the cold overlying air began to fall and crowded up the warm, light stratum beneath.

The scene was one of great beauty. In the eight or ten acres of the lake in view there would be a great number of these miniature columns of mist standing in relief against the dark pines in the background and as erect as they.

ADDITIONAL OBSERVATIONS OF THE ST. KITTS, W. I., HURRICANE.¹

By W. H. ALEXANDER, Observer.

About noon of Thursday, September 7, the wind changed from the northeast to the north, from which direction it blew steadily with an average velocity of 17 miles per hour until 2 a. m. of the 8th, when it began varying between north and northwest and increasing in force. About 5 a. m. it set in steadily from the northwest and continued from that direction until 1 p. m., when it began shifting to the west and increasing rapidly in force. From 1:45 to 3:40 p. m. the wind came from the west with an average velocity of about 36 miles per hour. At 3:40 p. m. it shifted to the southwest and soon reached verifying velocity. About 3:15 a. m. of the 9th, the wind began blowing from the south, and by noon it was coming steadily from that direction.

¹ From a second report by Mr. Alexander, we copy the following additional details, received too late to be inserted in the chapter on Forecasts and Warnings.